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CAP ANALYSIS

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November 18, 2002

Via Hand Delivery

Robert A. McGuire
Associate Administrator for Hazardous Materials Safety
Research and Special Programs Administration
U.S. Department of Transportation
400 7th Street, SW
Washington, DC 20590-0001

Re: Request for Exemption for Valence Technology's N-Charge Battery Pack

Dear Mr. McGuire:

Pursuant to 49 CFR § 107.101, I am writing to request an exemption from the U.S. Hazardous Materials Regulations (HMR) that would allow Valence Technology, Inc. ("Valence", "Valence Technology") to ship its lithium ion "N-Charge Battery Pack" in accordance with the packaging specifications described in Exhibit A, attached hereto, rather than a Class 9 hazardous material[1]. Valence Technology requests the exemption for shipping by road, air, and sea for a period of five years.

Since June 21, 2001, when the Research and Special Programs Administration (RSPA) of the United States Department of Transportation (DOT) issued a final rule as part of its regular harmonization process with international transportation regulations, it has regulated the transportation of certain lithium ion rechargeable batteries as hazardous materials. (*See* 66 Fed. Reg. 33315). Citing two fires involving certain types of lithium *primary* batteries in 1999 and 2000, and the advantages of harmonizing international transportation regulations, RSPA recently proposed changes to these regulations. (*See* April 2, 2002 Notice of Proposed Rulemaking (NPRM), 67 Fed. Reg. 15510.) RSPA has not yet promulgated a final rule concerning these proposals nor has it yet submitted a Paperwork Reduction Act approval request to the Office of Management and Budget (OMB) concerning these changes. One change proposed by RSPA would, for the first time, unnecessarily require Valence's N-Charge Battery Pack to be transported as a Class 9 hazardous material, which for Valence and its customers would be expensive and burdensome, and would undercut in the marketplace the significant safety advantages these batteries provide.

Currently, the N-Charge Battery Pack is excepted from regulation as a Class 9 hazardous material because it contains less than 25 grams of equivalent lithium content and passes the

[1] The N-Charge Battery Pack would be regulated as a Class 9 hazardous material starting in 2003 if RSPA issues a final rule on lithium batteries as it has proposed.

appropriate tests specified in the UN Manual of Tests and Criteria. If the changes proposed for the HMR go into effect in 2003, however, lithium ion batteries containing more than 8 grams of equivalent lithium content no longer will be excepted from regulation under 49 CFR § 173.185. Because Valence Technology's N-Charge Battery Pack contains 12 grams of equivalent lithium content it therefore would require a Class 9 hazardous material designation *(Lithium batteries, UN 3090, Class 9, PG II)* in 2003. Valence had hoped that an ongoing reevaluation of the hazards posed by lithium and lithium ion batteries in transportation that was initiated by RSPA in September 2000, would demonstrate to RSPA that substantial technological and safety advancements have been made to lithium ion batteries which could obviate the requirement for a Class 9 designation for consumer lithium ion batteries. One such development over the past few months has been the development and commercialization of Valence Technology's Saphion™ phosphate technology in the N-Charge Battery Pack. Apparently, this was RSPA's intent as well, but they decided that they would propose these changes without having completed the reevaluation. "[W]e believe that it is in the best interest of safety and international commerce to amend the HMR at this time based on the amendments to the UN Recommendations[2]." (*See* 67 Fed. Reg. 15512).

We believe that RSPA's reevaluation of the hazards posed by lithium ion batteries in transportation will show that with regard to safety matters, particularly those associated with fires, impacts, overcharging, temperature variances and short circuits, there are significant differences among lithium ion batteries. We strongly believe that Valence's N-Charge Battery Pack is the safest lithium ion battery available on the market today. It was designed and developed to address the concerns that have led RSPA to regulate the transportation of lithium ion batteries. The N-Charge Battery Packs:

- Are virtually fireproof. (See the comparison to another commercial lithium ion battery in the attached video that would not require a Class 9 designation.);
- Do not release oxygen gas upon decomposition as readily as lithium cobalt oxide based lithium ion batteries;
- Do not short-circuit upon much greater impacts than current tests require;
- Do not catch on fire if over-charged; and
- Are very stable in temperature variance tests.

In addition, Valence Technology proposes to ship only one N-Charge Battery Pack per package (total gross weight – 1.35 kilograms). (See Exhibit A for complete packaging specifications.) By contrast, the NPRM would allow packages of Class 9 lithium ion batteries on passenger aircraft that weigh up to 5 kilograms (gross).

Furthermore, if new regulations go into effect in 2003 as proposed, there will be new marking, packaging, and shipping paper requirements for packages with more than 12 lithium ion batteries if each battery contains less than 8 grams of equivalent lithium content. A package with 12 or fewer of these batteries would be excepted from these new requirements. This

[2] The "UN Recommendations" are the 12th Edition of the UN Recommendations on the Transportation of Dangerous Goods Model Regulations relative to the transportation of lithium/lithium ion batteries, as revised in December 2000. These revisions do not explain or provide the basis for the changes to the size exceptions for lithium ion batteries, the matter of concern to us.

unmarked, non-specification package could therefore contain up to **96 grams** of equivalent lithium content. By contrast, Valence Technology proposes to ship only one N-Charge Battery Pack per package, so that the total equivalent lithium content per package shipped would be only **12 grams**, substantially less than the **96 grams** noted above.

Valence, of course, would continue to comply with all other provisions of RSPA's regulations concerning lithium batteries, including the revised UN Manual of Tests and Criteria.

To further support this request for an exemption, enclosed is information on the N-Charge Battery Pack (and component cells), its composition and chemistry, and test data. Also enclosed is a video showing the N-Charge Battery Pack being subjected to various tests. The lithium ion battery to which Valence's N-Charge Battery Pack is compared in the video has about 6.5 grams of equivalent lithium content, and, therefore, would be excepted from the Class 9 hazardous material transportation requirements under RSPA's NPRM. As you can see from the video and the test data, the N-Charge Battery Pack is safer and much less likely to burn. We welcome the opportunity to meet with you and your staff to explain the data and video.

We look forward to the opportunity to meet you and your staff to discuss this matter. At that meeting, representatives from Valence Technology will provide samples of the N-Charge Battery Pack. If you have any questions, please contact me at 202/383-7163.

Thank you for your assistance.

Sincerely,

George A. Kerchner

cc: Casey Keen, Valence Technology (w/ encl.)
Roger Williams, Valence Technology (w/ encl.)
Dr. Richard Tarr, US DOT/RSPA (w/ encl.)
Dr. Charles Ke, US DOT/RSPA (w/ encl.)
Dr. Spencer Watson, US DOT/RSPA (w/ encl.)
David Weinberg (w/o encl.)

EXHIBIT A

Applicant:

Valence Technology, Inc.
6504 Bridge Point Parkway
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Austin, Texas 78730
Phone: 512-527-2900
Facsimile: 512-527-2910

Person Applying on Behalf of Applicant

George A. Kerchner
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The CapAnalysis Group
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Packaging Specifications for N-Charge Battery Pack

- 1 N-Charge Battery Pack per package
- Fiberboard combination packaging will be used
- Packaging will be capable of withstanding a 1.2 meter drop test in any orientation without damage to cells or battery contained in the package, without shifting of the contents that would allow short circuiting, and without release of package contents.

Valence Technology, Inc.
PurePower

Valence Technology, Inc. Exemption Application to DOT

Valence Technology, Inc.
PUREPOWER

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INTRODUCTION

Valence Technology, Inc. (Valence), the applicant in this request for an exemption, is a leader in the development and commercialization of Saphion™ lithium ion technology and lithium ion polymer rechargeable batteries. Valence has more than 722 issued and pending patents worldwide, including 254 issued in the U.S. Valence is a U.S. based company with facilities in Austin, Texas, Henderson, Nevada and Mallusk, Northern Ireland and is among the dwindling number of U.S. companies in the rechargeable battery field competing against the large Japanese and Asian companies that dominate the field. Valence is committed to the development of advanced technology for the growing rechargeable battery market. Valence continuously strives through its world-class team of scientists at its state-of-the-art research facility in Henderson, NV, to exceed expectations for high-powered, safe, long lasting, cost effective energy solutions.

Valence has been the pioneer in the development of a revolutionary lithium ion technology that uses phosphate based cathode materials that offer safety benefits comparable to nickel cadmium (Nicad or NiCd) and nickel metal hydride (NiMH) technologies while delivering lithium ion performance. Because of intrinsic safety and performance characteristics Saphion technology is expected to have a long term impact on the battery industry and reestablish US leadership in this field. .

Valence introduced Saphion into commercial markets in mid 2002 and the technology has generated significant interest in consumer and industrial applications. Saphion™ technology will greatly expand the market opportunity for rechargeable batteries, will better serve existing markets and will open the door to new markets for lithium ion that previously were not available because of safety concerns and the costs for safety circuitry that traditionally has been required. Saphion™ technology addresses the major safety weaknesses of existing lithium ion alternatives in both use and transportation while offering a solution that is competitive in cost and performance.

Today, lithium ion batteries are widely used but limited to small format applications in the computer, communications and consumer markets in products such as cellular phones, personal digital assistants and other mobile appliances. Saphion™ lithium ion technology not only provides a highly differentiated and safer technology for these current applications, but the high energy density, long life expectancy and high efficiency of the phosphate-based technology affords the opportunity to expand into large format applications in sectors such as the automotive, telecommunications and industrial. Large format cells are ideal for many high energy, high power applications such as remote power supplies, load leveling systems and vehicles.

Beyond these applications, Saphion responds to the growing requirements of the portable market. Whether included inside the product or as an accessory to provide increased battery life, Saphion is the ideal technology to answer the challenges set by the new power requirements of key notebook components. The N-Charge power system is the first product using Saphion technology. It launched this year to respond to the increasing power demand of mobile users.

This application has been submitted to allow Valence to ship the N-Charge power system as a non-regulated battery technology, similar to existing lithium ion notebook battery packs. Although the N-Charge system exceeds the proposed threshold limit of 8g equivalent lithium content, it is much safer for use and transportation than products that fall below this limit.

The attached documents and appendices, detail the fundamentals of Saphion technology and describe the result of the in-depth internal and independent 3rd party testing that demonstrate the inherent safety characteristics of the technology. Valence is committed to the development of advanced technology for the growing rechargeable battery market.

Valence has been focused on the creation of safe, cost-effective battery technologies for many years. Saphion™ lithium ion technology is the most recent and exciting product of these efforts. It utilizes environment-friendly materials, i.e., phosphate-based cathode material, and offers the greatest combination of energy, cost, safety and environmental characteristics. Saphion™ technology capitalizes on the energy density and efficiency of lithium ion with a number of added benefits, including excellent cost/performance and safety characteristics. Saphion™ technology can be used in wound cylindrical, wound prismatic and polymer battery construction types, among others.

Valence's phosphate-based Saphion™ technology possesses safety characteristics that are fundamentally superior to those of lithium ion technology made with other cathode materials. The breakthrough feature of Saphion™ technology is its exceptional thermal and chemical stability.

- These unique chemical properties render Saphion™ technology energy solutions virtually incombustible in the event of mishandling during charge or discharge.
- Saphion™ technology is extremely stable under overcharge or short circuit conditions and has the ability to withstand high temperatures without decomposing.
- When abuse does occur, the phosphate-based cathode material will not burn and is not prone to thermal runaway.

As can be seen by the Abuse Studies discussed later in this application, Saphion™ technology exhibits unrivaled beneficial safety characteristics when subjected to the standard transportation abuse tests. These safety characteristics present Saphion™ technology as the safety choice in use and transportation.

Valence Technology, Inc.
PUREPOWER

The Safety Advantages of Valence's Saphion Technology

Prepared for the US DoT
(Technical white paper)

M.Y. Saïdi, Ph.D. and J. Barker, Ph.D.

Valence Technology Inc.,
301 Conestoga Way
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USA

Summary:

Among lithium transition metal oxides, $LiCoO_2$ has long been the chemistry of choice in current commercially available lithium ion batteries. This was a natural outcome due to its demonstrated performance in many of today's electronic consumer products. A primary challenge in designing larger format lithium ion batteries has been achieving safe behavior under normal and abusive conditions. The choice of cathode materials used in these batteries has been found to have a profound effect on safety behavior and $LiCoO_2$ in particular, demonstrates very poor thermal stability. This instability is directly related to the ease of oxygen liberation from the $LiCoO_2$ structure. To address these limitations, Valence Technology has spent several years developing an intrinsically safe cathode material, recently introduced as a novel phosphate, $LiFe_{1-x}Mg_xPO_4$ – the core of Valence's proprietary Saphion Technology. Even under severe abusive conditions this material will not liberate oxygen and therefore does not pose any significant safety hazard. In the attached document, an in-depth discussion focusing on the fundamental safety of the phosphate material is presented. This safety behavior is compared with that of $LiCoO_2$.

Background:

During the last few years, rechargeable lithium ion batteries have reached an established commercial status with a production rate of several million units per month. Although research on cathode materials has primarily focused on lithium transition metal oxides, currently $LiNiO_2$, $LiMn_2O_4$, $LiCoO_2$ have successfully been incorporated in lithium ion cells with $LiCoO_2$ being by far the most commercially available, particularly in small portable electronics applications because of its higher energy density, ease of synthesis and reasonable rate capability. Thermal stability studies of $LiNiO_2$, $LiMn_2O_4$, $LiCoO_2$ have shown that $LiMn_2O_4$ spinel to be the most stable.[1,2] However, poor electrochemical performance of the spinel has prevented this material from being the material of choice in batteries. In spite of the fact that $LiCoO_2$ is widely accepted commercially, its cost, low abundance in the earth's crust and environmental concerns remain severe problems.

An iron-based cathode would be ideal and would answer both the economic and environmental concerns and open the long-awaited window for large platform applications. As a result, in the last few years, researchers have put a significant effort into developing an iron-based cathode. Most of the focus has been dedicated on developing an Fe analog to the layered $LiCoO_2$ system in order to alleviate the safety and thermal stability concerns associated with the latter. However, this concerted effort has not met the desirable electrochemical performance required for a viable cathode material. [3,4]

Recently, a series of materials incorporating large poly-anions, such as PO_4 have been investigated, most notably the rhombohedral modification of Lithium Iron phosphate, $LiFePO_4$.[5,6] $LiFePO_4$, with its high available capacity of 170mAh/g, compared to 148 and 150mAh/g for $LiMn_2O_4$ and $LiCoO_2$, respectively, is currently regarded as the most promising cathode material for small low-power and large platform applications. Low cost, non-toxicity, abundance of Fe in the universe, excellent thermal stability, safety characteristics and very good electrochemical performance add to an already long list of desirable characteristics for lithium iron phosphate as a choice for a cathode material. Furthermore, the safety properties of the magnesium-containing material (Saphion™ technology, $LiFe_{1-y}Mg_yPO_4$ referred to herein as P1a) have been demonstrated to be very similar to those described for $LiFePO_4$. Magnesium is inert and accordingly, the discussion herein will be limited to the iron phosphate compound.

The structural advantage:

In the $LiFePO_4$ structure the oxide ions form a hexagonal close packing (hcp) arrangement. The metal (Fe) ions form zigzag chains of octahedra in alternate basal planes bridged by the tetrahedral phosphate groups (PO_4). The lithium atoms occupy octahedral sites, located in the remaining basal planes. The strong covalent bonding between the oxygen and P^{5+} to form $(PO_4)^{3-}$ units allows for greater stabilization of the structure compared to layered oxides, e.g. $LiCoO_2$ where the oxide layers are more weakly bound. This strong covalency stabilizes the anti-bonding Fe^{3+}/Fe^{2+} state through an Fe-O-P inductive effect. Consequently, oxygen atoms are a lot harder to extract, Figs. 1 and 2.

Under normal abuse conditions there is no likelihood for phosphate decomposition and therefore no chance for oxygen liberation from the structure. Only under extended and extensive heating (typically > 800°C) can condensation (with oxygen release) of the monophosphate moiety occur, allowing production of condensed phases such as the diphosphates and triphosphates.

Furthermore, upon removal of lithium, Li_xCoO2 undergoes an anisotropic (non linear) expansion of the unit cell (for $x > 0.5$); whereas in $LiFePO_4$, the expansion of the unit cell is isotropic[7]. This particular anisotropic behavior for $LiCoO_2$ is particularly important for battery safety in that it affects the structural integrity of the material and hence its safety. Removal of all the lithium available in $LiFePO_4$ does not result in any structural modification of the material.

This stability applies for all states of charge i.e. it does not depend on the amount of lithium extracted from the structure. Certainly the thermal stability of the $LiFe_{1-y}Mg_yPO_4$ is far better than for partially de-lithiated $LiCoO_2$. Saphion chemistry i.e., $LiFe_{1-y}Mg_yPO_4$ means that by design the amount of lithium extracted is limited. Furthermore, it is also generally understood that the transition metal mono-phosphates are close to refractory in nature with melting points often far in excess of 1000°C, thereby adding to their safety characteristics under thermal abuse conditions.

Using DFT[8,9] *appendix A*, we have attempted to model the stability of phosphate materials by their propensity to lose oxygen. It is this oxygen that would assist any reactions ensuing from battery operation under certain abuse conditions. Therefore, one way to evaluate a material's safety would be to model its resilience towards oxygen loss and verify the findings experimentally.

Oxygen Defect Energies:

Oxygen defect energy is the energy associated with removing oxygen from the structure and converting it to oxygen gas. Oxygen defect energy is calculated by treating O_2 as an ideal gas and calculating the oxygen chemical potential, assuming the defect energy is a linear function of composition.

Compound	Edefect (x=0)	Edefect (x=1)
Olivine		
LixFePO4	1.6	1.8
LixCoPO4	0.3	1.8
Layered		
LixCoO2*	0.2	1.6
LixNiO2*	0	???

Table 1: Oxygen defect energies for olivine phosphates and layered oxide cathode materials.

This data is in accordance with the electro-negativity of the metals involved. When oxygen is pulled from the structure, the available electrons will go to the most electro-negative ion, Co^{3+} in this case. Defect electrons generally go to phosphorous, yielding similar (and high) defect energies. Co^{3+} is so highly electronegative that defect electrons reduce Co, creating a low defect energy. It is clear that for x=o (i.e. the charged state), iron phosphate is the most stable of all the chemistries currently used in lithium ion batteries with $LiCoO_2$ and $LiNiO_2$ having the highest propensity of losing oxygen in the charged state.

Electron Density Maps:

An electron density map is a way of looking at the distribution of negative charge donated by the removed oxygen, depicted as blue color in Figs. 3a and b. When a metal is less electro-negative, there is less hybridization between the metal ion and the oxygen orbitals as clearly illustrated in the case of $LiFePO_4$. On the other hand, there is a strong orbital overlap or hybridization when the Co^{3+} ion is involved. Direct estimation of the magnetic moments for Fe^{3+} and Co^{3+} are found to change accordingly (i.e. no change for $LiFePO_4$). The redox-couple is further corroborating evidence since it is a measure on how energies change when electrons are added to a metal, whereby the higher the redox couple, the easier it is to create oxygen defects.

Fe^{3+}/Fe^{2+} = 3.5 V vs. Li/Li^+
Co^{3+}/Co^{2+} = 4V vs. Li/Li^+ (in $LiCoO_2$) and 4.8V vs. Li/Li^+ (In $LiCoPO_4$)

Oxygen Defect Concentration:

Fig. 4 is a calculation of the O defect concentration for layered $LiCoO_2$ and the Olivine $LiFePO_4$ as a function of lithium composition. Because of the extreme sensitivity of the exponential dependences involved, these graphs are only qualitative. However, we believe that the difference is clear. When fully discharged, the two materials have comparable O defect concentrations. However, upon charging (removal of lithium), the lithium cobalt oxide becomes unstable at a faster rate than its phosphate counterpart. Upon full charge, the O defect concentration differs by several orders of magnitude. This is further discussed below.

Thermal Stability:

With higher energy density batteries available, safety is the paramount concern for consumer batteries and more advanced safety technology is required. The behavior and thermal stability of the cathode in the charged state is essential in determining the safety of the final cell. There are various approaches in evaluating the safety of cells under abuse conditions. The over-charge conditions for example may lead to thermal runaway. It is therefore important to understand the cause of this thermal runaway since it is closely related to the temperature rise in the cell. Previous work has shown that the electrolyte decomposition becomes significant when voltages exceed 4.5V, and that the reaction of the cathode material with the electrolyte decomposition products happens with large heat generation resulting in cell failure and possible hazardous cell rupture.[10]

Over-charging of the cathode materials in lithium ion batteries can lead to a variety of electrochemical reactions depending on the specifics of the system's chemistry. For example, solvent oxidation due to the abnormally higher cathode voltage, and formation of inert material may result. Thermal abuse of the cathode will lead as in the case of $LiCoO_2$ to oxygen loss from the oxide structure and will increase the pressure in the cell and possibly assist any combustion reaction because of the accumulation of flammable gas mixtures in the cell. This results in a serious safety concern. It has been established that for the most common cathodes used today, $LiCoO_2$, $LiNiO_2$, $LiMn_2O_4$, the following decomposition reactions occur for charged cathodes under abuse conditions.[1]

$$Li_xCoO_2 \longrightarrow (1-x)/3[Co_3O_4 + O_2(gas) + xLiCoO_2] \quad (1)$$

$$Li_{x<0.3}NiO_2 \longrightarrow LiNi_2O_4 + O_2(gas) \quad (2)$$

$$\lambda\text{-}MnO_2 \longrightarrow \tfrac{1}{2} Mn_2O_3 + \tfrac{1}{4} O_2 (gas) \quad (3)$$

Therefore, for all the lithium transition metal oxides used today in lithium ion batteries, oxygen loss is a result of the material decomposition. The exothermic behavior and related oxygen liberation reaction for the cobalt system is a particular problem. This reaction is particularly severe when the cathode is in a charged (de-lithiated) condition.[11-13]

Differential Scanning Calorimetry (DSC) offers a convenient way of studying the thermal stability of charged cathodes under controlled conditions whereby the rate of temperature rise (23-400^{0}C) is controlled and the heat generated is estimated. Fig. 5 illustrates the results. The exothermic heat flow for $LiFePO_4$ was observed around 270^{0}C and the total equivalent heat generated is 124 J/g (Joules per gram of material). In contrast, the total heat generated for the equivalently charged $LiMn_2O_4$, $LiCoO_2$ and $LiNiO_2$ is 240, 570 and 890 J/gr respectively. The event onset occurs earlier for the oxide materials than the phosphate based cathode (the same amount of Lithium or mAh/gr equivalent was removed electrochemically from all the cathodes and the same electrolyte EC:DMC (2:1) was used for all the tests, Fig. 4. The remarkable thermal stability of $LiFePO_4$ is reflected in its very small exotherm compared to the currently commercially used $LiCoO_2$. This material will therefore produce batteries with a high tolerance to very high temperatures.

Conclusions:

Fundamental properties of lithium iron phosphate, the core of Valence's Saphion technology make for an intrinsically safe cathode material for lithium ion applications. When fully charged, no excess lithium is left in the cathode (unlike $LiCoO_2$ where 50% still remains). The Redox voltage is low enough to ensure no electrolyte decomposition occurs. We – and others – have also demonstrated that this material has a high resilience to oxygen loss, reducing the likelihood of any significant exothermic event upon heating. Furthermore, Valence's polymer technology provides a system with no free electrolyte, unlike commercially available liquid based batteries, thereby further adding to its safety characteristics.

Appendix A:

All calculations are performed in the Local Density Approximation (LDA) or Generalized Gradient Approximation (GGA) to Density Functional Theory as implemented in the Vienna Ab Initio Simulation Package (VASP).1,2 The nuclei and core electrons are represented with ultra-soft pseudopotentials and all structures are fully relaxed with respect to internal and external cell parameters unless explicitly stated. The wave functions are expanded in plane waves with kinetic energy below 405 eV. Brillouin zone integration of the band structure is performed with a Monkhorst-Pac mesh of k-points large enough to give adequate convergence. Unless otherwise stated, the charge density is ferromagnetically spin-polarized. This is an approximation, since most oxide systems are anti-ferromagnetic, but the effect of the approximation on such quantities as oxygen defect energies and Li activation barriers is unlikely to be significant.

References:

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[7] Jan. N. Reimers and J. R. Dahn, *J. Electrochem. Soc.*, **139** (1992) 2091

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[10] Yoshiyasu Saito, Kiyonami Takano, Akira Negishi, *J. Power Sources*, **97-98** (2001) 693.

[11] A. Yamada et al. in *J. Electrochem. Soc.* **148**, A224, (2001).

[12] A. Andersson et al. in *Electrochem. Solid State Lett.* **3**, 66, (2000).

[13] J.R. Dahn (Dalhousie University, Nova Scotia, Canada) presented a direct comparison of the thermal behavior of the $LiCoO_2$ and $LiFePO_4$ cathodes using the ARC technique, Wolsky Conference, Florida in 2001.

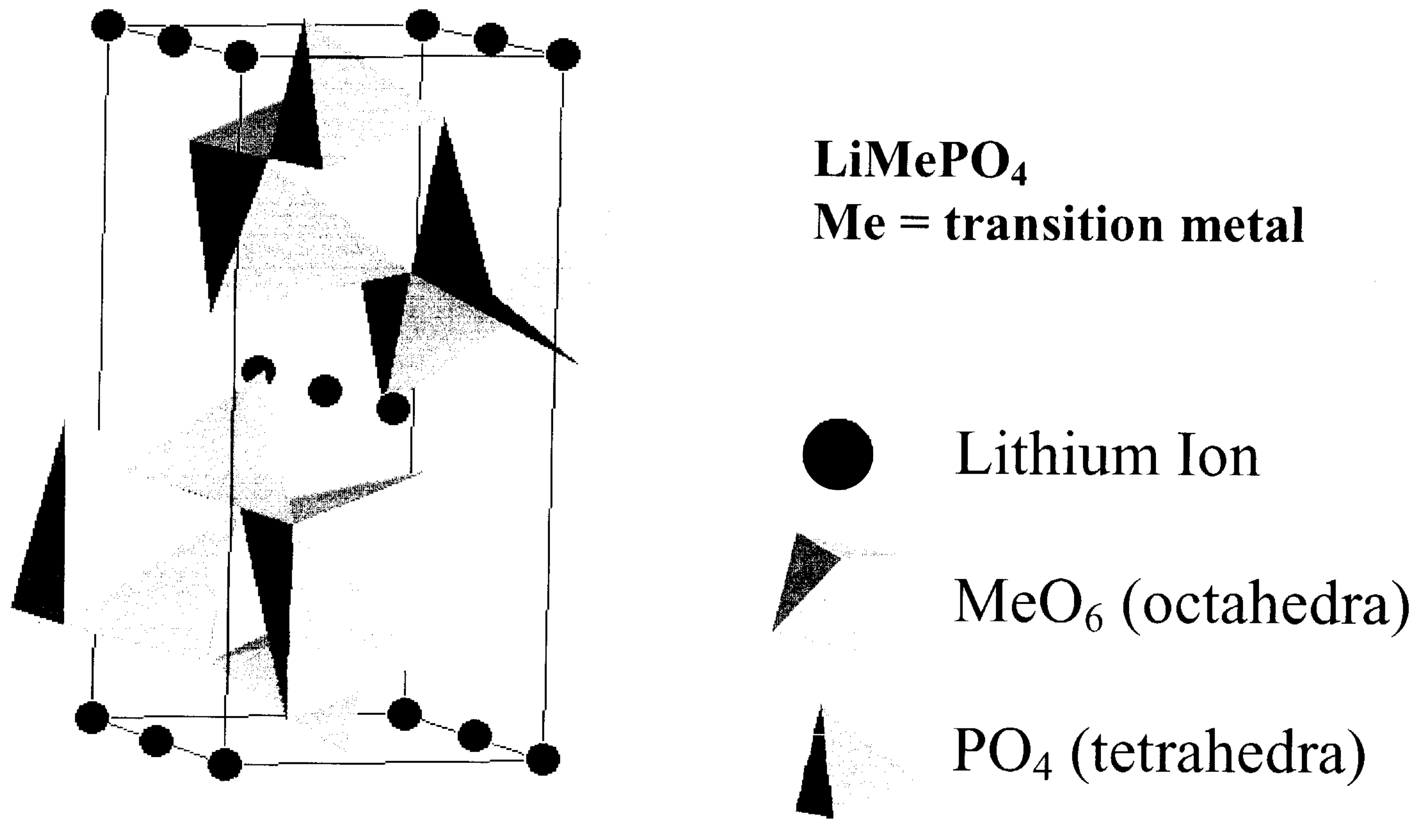


Fig. 1: $LiMePO_4$ unit cell representation (shown is corner sharing of PO_4 and MeO_6)

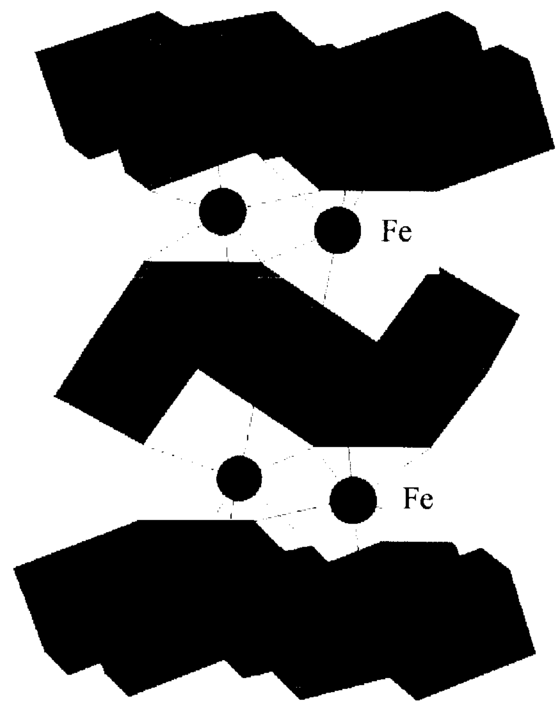


Fig. 2: $LiMePO_4$ unit cell representation (Metal ions are represented by circles)

$\rho(Li0FePO4\text{-}x) - \rho(Li0FePO4)$ [x=1/16]

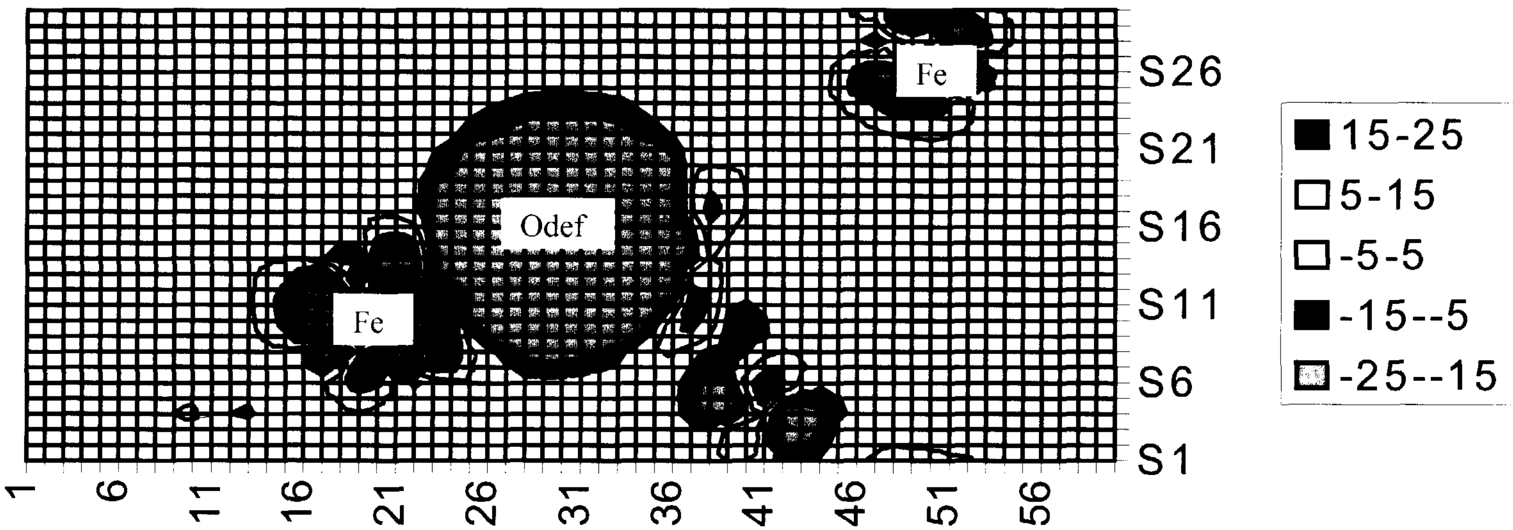


Fig.3a: Electron-density map for $LiFePO_4$

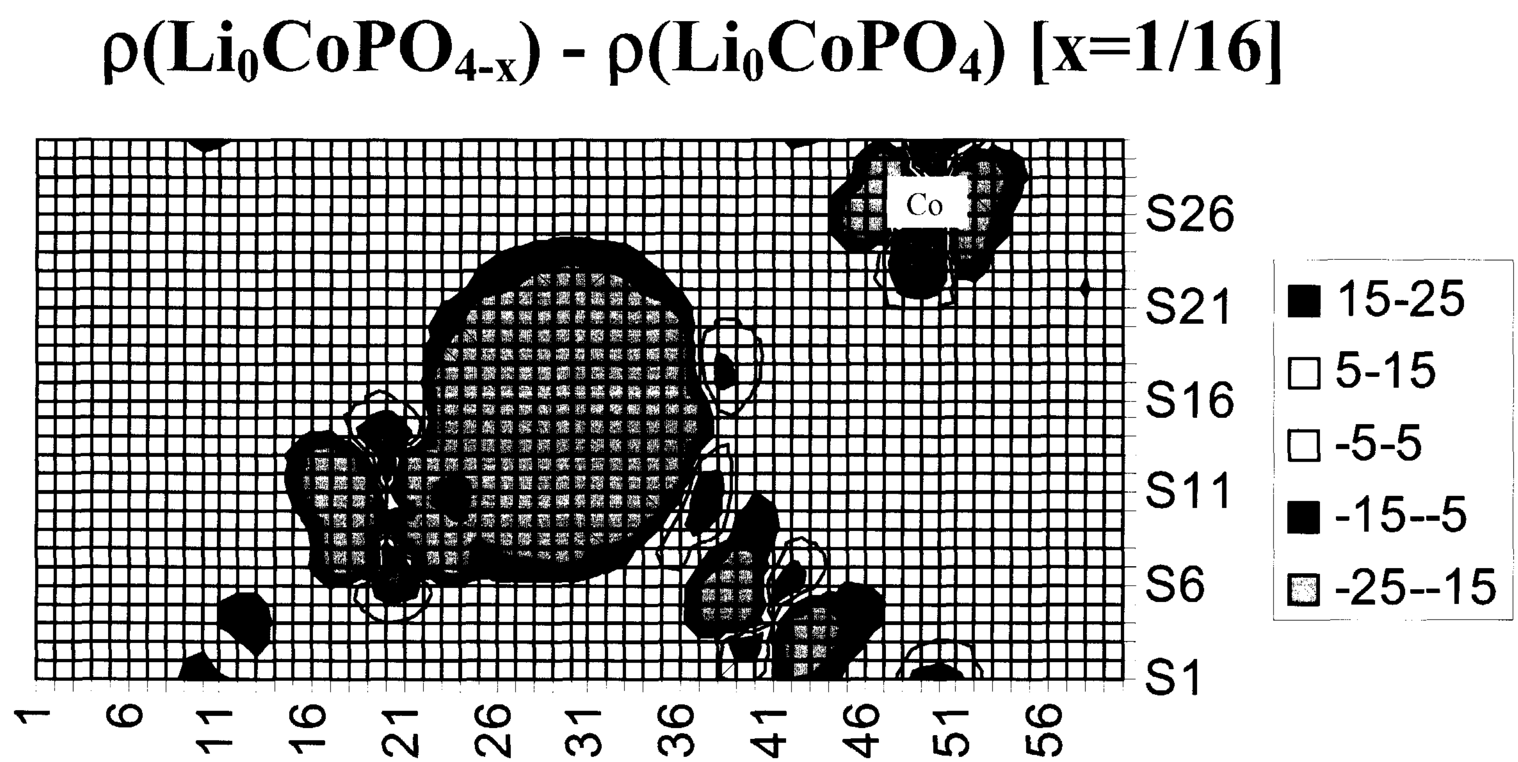


Fig.3b: Electron-density map for $LiCoPO_4$

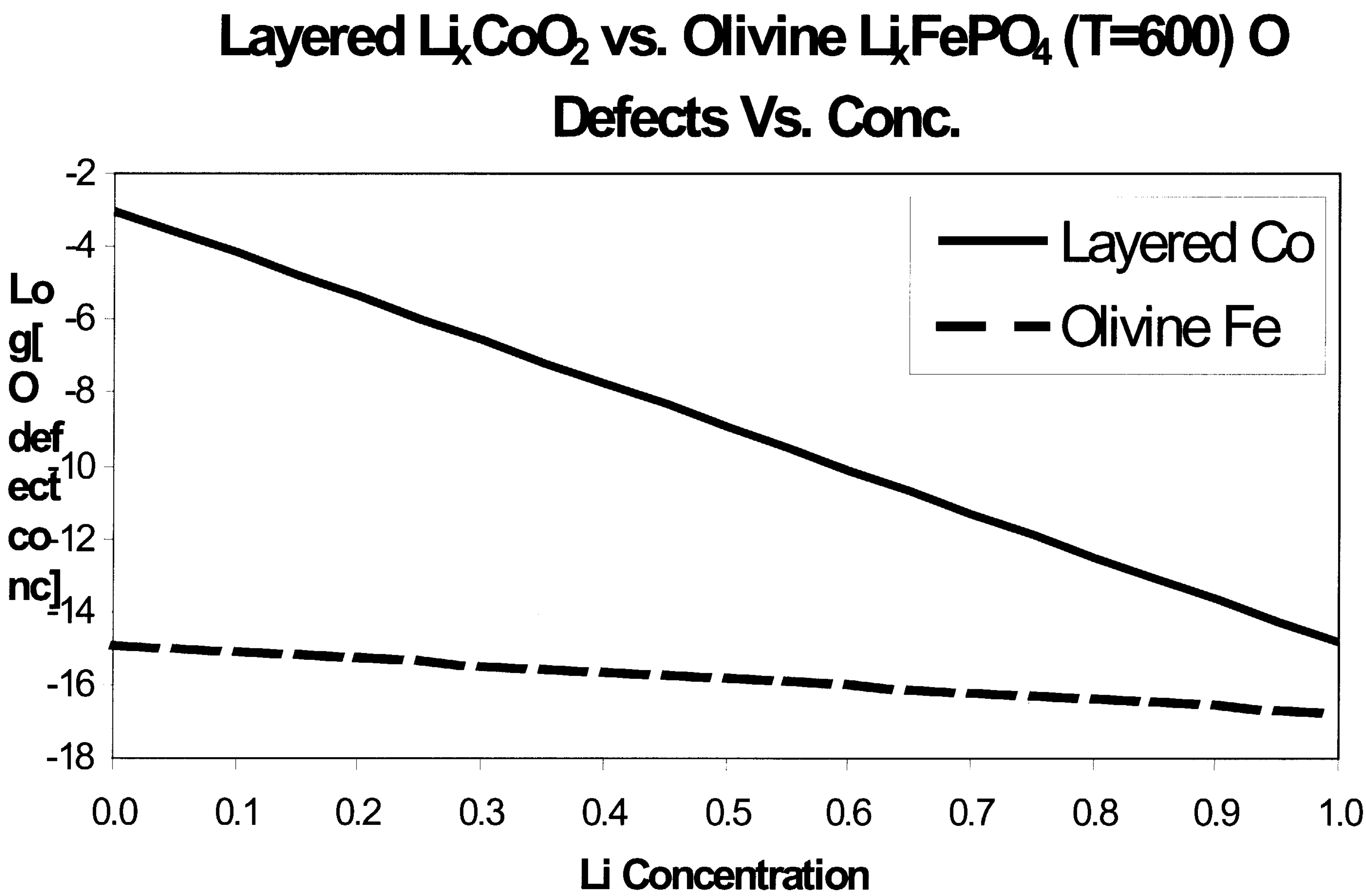


Fig. 4: Layered LixCoO$_2$ vs. Olivine LixFePO$_4$ (T=600) O Defects Vs. Concentration.

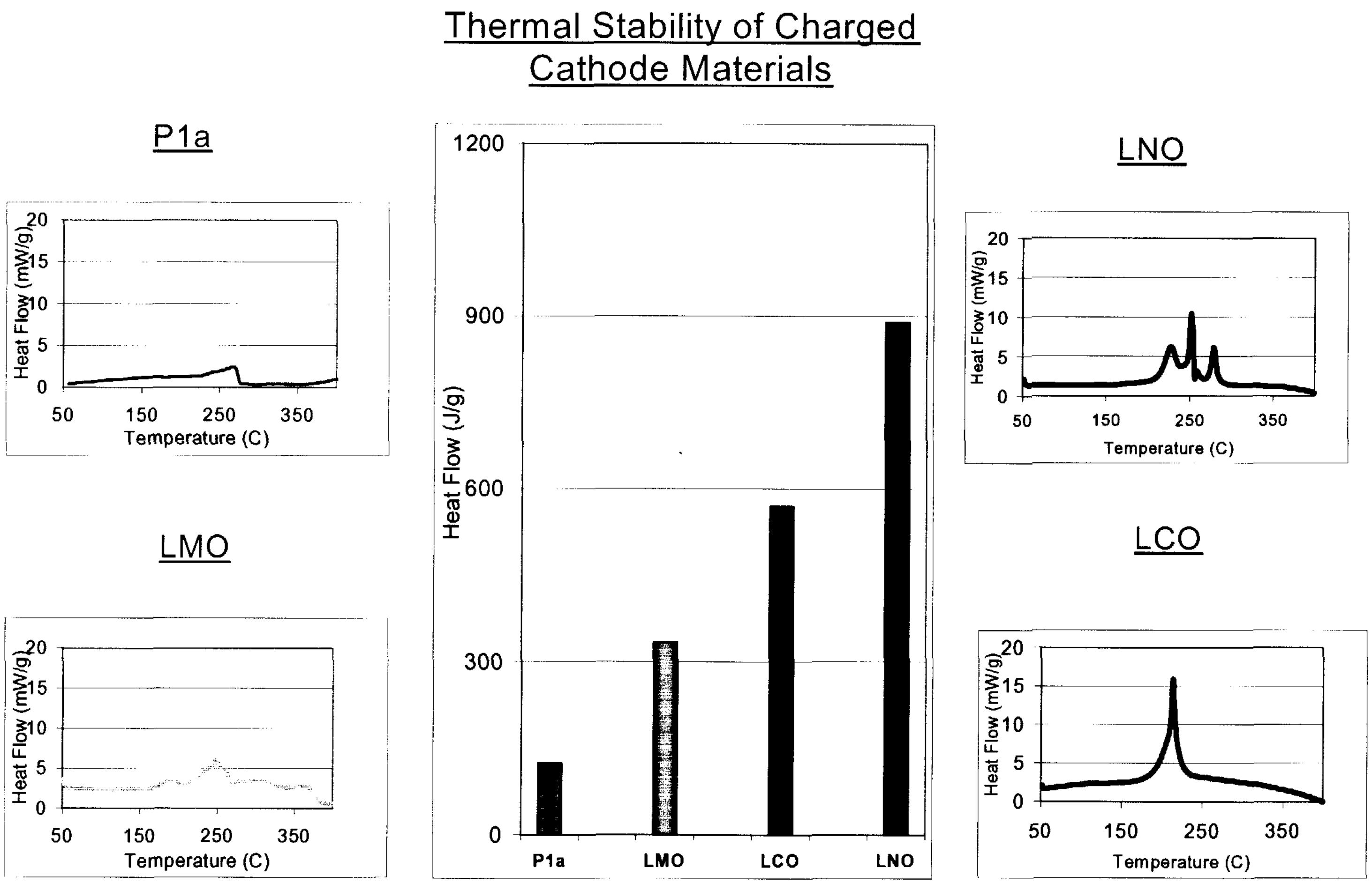


Fig. 5: DSC profiles for various charged cathodes from 23C to 400C at a heating rate of 5C/mn

Valence Technology, Inc.

PUREPOWER

Saphion Abuse Testing Summary

November 1, 2002

Overview

Saphion lithium ion polymer batteries are a culmination of years of effort at Valence Technology to produce large format rechargeable batteries with improved safety characteristics over existing li ion chemistries. When Valence's proprietary, phosphate based cathode powders are combined with patented polymer battery production techniques, the result is a battery that performs like no other when exposed to abusive environments. Throughout development and continually since its introduction into the consumer marketplace, Saphion products have undergone rigorous testing both internally and at third party agencies. Head-to-head with all other li ion cells and batteries, there is no comparison to the safety of Saphion products. The following document will attempt to summarize the abuse testing to date on the N-Charge Power System including the VP53109133 component cells.

Third Party Certifications for N-Charge Product Line

Models 065H001 and 130HL01

Certifications	**Report References**
UL 1642 – Standard for Lithium Batteries, Third Edition, 1995 (VP53109133 Component Cells)	File MH25828
UL 2054 - Standard for Household and Commercial Batteries, First Edition, 1997	File MH28367
Error! Unknown switch argument. TUV-GS, cTUVus - EN 60950: 1992+A1+A2+A3+A4+A11	Certif. No. S 2273464
CB Report, IEC 60950:1991+A1+A2+A3+A4, 2nd Edition - TUV Rheinland of North America	Ref. Certif. No.: US-TUVR-1243
FCC - CFR47, Part 15, Subpart B Unintentional Radiators	DOC Number: 052002
Error! Unknown switch argument. CE-marking - conformity with: EMC: CISPR22:1997 "Information technology equipment-Radio disturbance characteristics-Limits and methods of measurement" Class A CISPR24:1997 "Information technology equipment-Immunity characteristics-Limits and methods of measurement" Safety: UL 2054 and IEC 60950	N/A1

Table 1 - N-Charge Product Line 3rd Party Certifications

Tests and Results

Altitude Exposure

Valence Li Ion Polymer cells are vacuum packaged in a robust, multi-layer packaging material. There is no burst disk safety device to be stressed by the pressure differential between the interior of the cell and the exterior. The test in the UN Manual of Tests and Criteria calls for storage for 6 hrs at a pressure of 11.6kPa (50,000ft altitude).

- Valence performed this test on 15 cells, 5 each at 0%, 50%, and 100% state of charge in preparation for UL testing. Subsequently, UL dropped altitude from the test plan for the VP53109133 based on their extensive experience testing other Valence Li Ion Polymer cells packaged by the same method.
- Test 1 of the UN test for the cells was performed in Valence's test lab. 10 units were stored at 0% and 10 at 100% with no apparent effect.

Thermal Cycling

Rapid transitions from very high temperature to very low temperature can stress mechanical connections and certain materials. Test 2 of the UN tests for lithium batteries is particularly brutal, swinging from +75°C to –40°C in less than 30 minutes. Not only is this 5°C hotter than UL, there is no 2 hour dwell time at 20°C to cushion the shock.

- Valence performed UL thermal cycling on 15 cells as a pre-cursor to testing at UL only to have UL cancel this portion of the test based on good experiences with other Valence cells.
- During UN testing of the VP53109133, 20 cells were temperature cycled by Valence
- 16 N-Charge samples were temperature cycled at Motorola Product Testing Services for that unit's UN testing

Vibration and Shock

A Valence Li Ion Polymer cell is almost solid state. The cell stack is heat laminated together even before a substantial vacuum is pulled inside the packaging. There is not even any free electrolyte within the cell. There is a greater hazard that a cell will be damaged by over tightening a bar clamp and denting the sample than there is from even the quite substantial vibration and shock profiles included in the UN tests. When component cells are assembled into the N-Charge battery pack, they are vulnerable to breaking loose within the enclosure and becoming damaged. Even if this did occur, there would be practically no risk of a hazardous condition resulting. This is proven by the impact, nail penetration, and short circuit testing that is repeatedly conducted upon and passed by these Saphion cells.

- Vibration and shock are tests 3 and 4 in the UN standard. 20 cells and 16 N-Charge batteries have passed these tests.

Short Circuit at Elevated Temperature

A fully charged cell or battery is discharged through a very low resistance, resulting in currents that push well beyond the typical operational specification. In the field, short circuits can be the result of improper handling or external component failures. Rapid heat build up in lithium ion cells due to the internal resistance to the current flow is normal. Conducting the test at 60°C increases the chance that this heating due to the current flow will push the components of the battery into thermal runaway.

Short circuit at room and elevated temperature is included in most third party certifications for lithium batteries. UL 2054 requires that, when discharged through a resistance of .1 Ohm maximum, the battery shall not explode, catch fire, or reach a temperature of greater than 150°C. The component Saphion cells of the N-Charge system can be subjected to this test with no protective circuitry and pass with maximum temperatures typically between 90°C and 100°C. The momentary short circuit current peaks near 90A when 21 mOhm is used for the resistance. Any lower resistance and the aluminum tab material fails open from the high current.

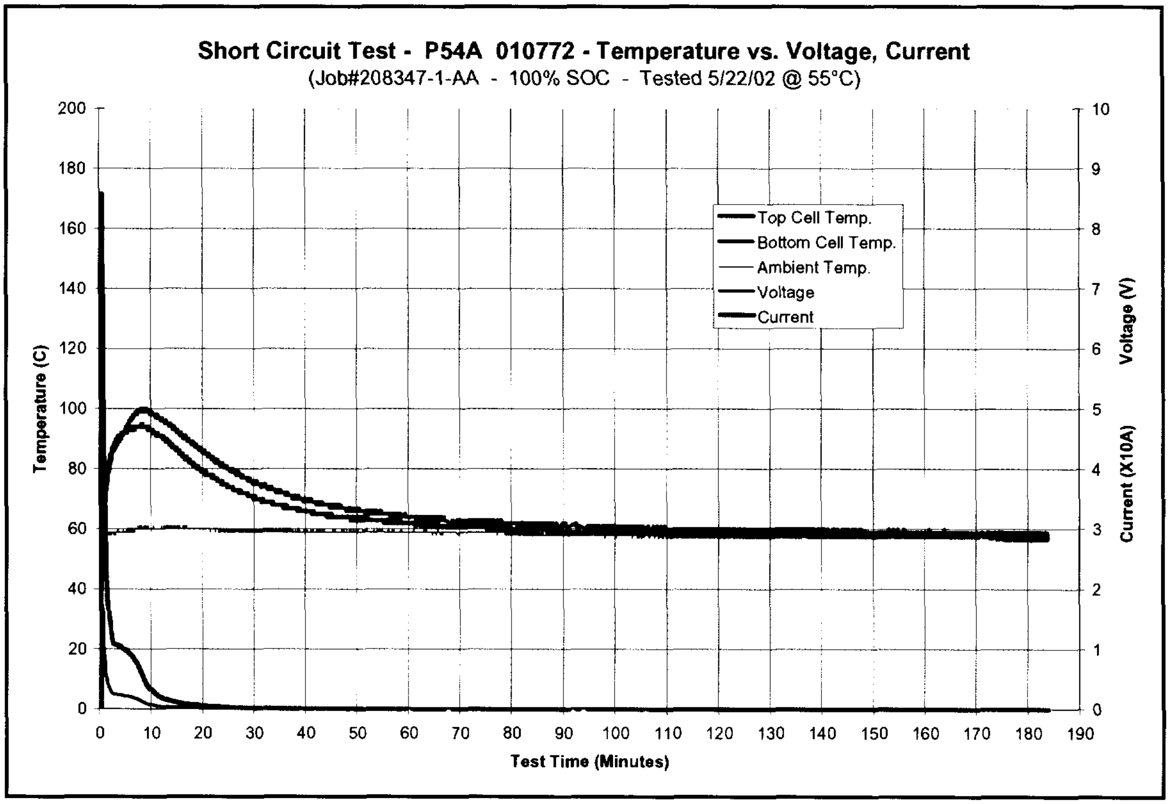


Figure 1 - Maximum Temperature Attained During UN Short Circuit Testing on Component Cells

Output current on the N-Charge system is limited to 5A maximum by a UL Recognized fuse. An external short on an N-Charge results in a blown fuse, and a 5 amp load results in a one hour or two hour discharge depending on the model. For added protection, if the output cable on the battery is removed, the connector is totally inactive. Active circuitry on the controller board communicates with the cable when it is present and reactivates the unit.

- Valence has conducted 60°C short circuit in at our Henderson Nevada laboratory 14 times independently (one blown tab) and at 55°C another 20 times as a part of the UN testing for the VP53109133 cell (10 at 0% SoC and 10 at 100%).
- Motorola Product Testing Services ran 5 tests at 23°C and 5 at 60°C acting as a testing agency for the UL 1642 recognition process.
- Underwriters Laboratories in Northbrook Illinois shorted 10 N-Charge units at 60°C and 5 at 23°C for our UL 2054 listing.
- TUV Rheinland of North America, during their fault simulation analysis of the N-Charge for IEC 60950, verified proper fuse operation 6 times and hard shorted 4 cells, blowing their tabs each time.

Round Bar Impact

For round bar impact, a 15.8mm diameter round bar is placed across the cell. From 61 cm above, a 9.1kg mass is dropped upon the bar. The result is a very violent impact that could easily cause a battery to short internally. The odds of this are increased dramatically when prismatic cells are placed on edge and subjected to this extreme abuse. Valence cells are not protected by a metal outer enclosure. After edge on, round bar impact, VP53109133's can closely resemble rather large bowtie pasta. Even so, the cells rarely even lose voltage immediately after this test.

- Motorola Product Testing performed flat impact on 5 samples as an agent of UL during 1642 recognition.
- Valence has performed the flat impact test on VP53109133's at 0% SoC 8 times and 50% SoC 6 times. It is standard procedure at Valence, even during UN testing, that a second impact be performed in a new location on the sample if no voltage drop or temperature rise is observed after the first.
- Edge testing at Valence has been executed 5 times on 0% SoC cells, 5 times at 50%, and 2 samples were impacted at 100% SoC.

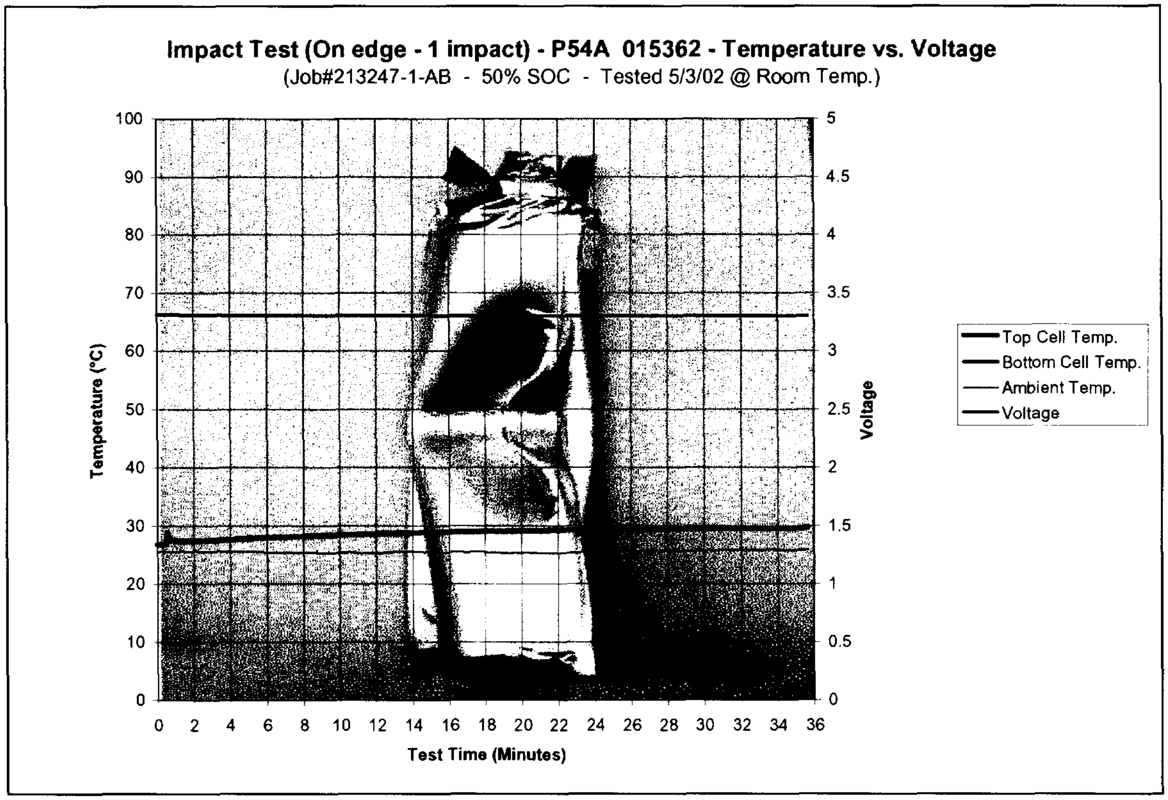


Figure 2 - VP53109133 After Edge Impact

Overcharge

Overcharging a lithium ion cell is a particularly severe, however realistic, form of abuse. User error with a charger or a component failure can cause voltage and current limits to be violated, resulting in a hazardous condition with most li ion chemistries. Saphion cells are protected by the chemical composition of their phosphate cathode from a violent response to simple overcharge. A fully charged Saphion cathode will have given up almost 100% of its supply of lithium ions whereas a cobalt based cathode still contains 50% in order to remain structurally stable. This redundant supply of ions can be pushed to the anode during overcharge, possibly plating out metallic lithium, and causing instability in the cathode.

While UL includes overcharge testing in its approvals, the UN test is quite severe at 2X the typical maximum charge voltage and current. For the VP53109133 this works out to be 7.3V and 10A if the test were required for cells. The N-Charge battery, which is charged via whichever laptop power supply the consumer is using, falls into the greater than 18V category. Per UN it is overcharged at 1.2X max voltage and 2X the current or 23.4V and 6A. The charge control circuitry within the N-Charge is scaled to handle this kind of input even though it is not typical. UN Test 7 conducted on an N-Charge unit results in a normal charge for the component cells within. The excess power that is supplied is shunted off as heat. There are hard limits programmed into the unit for maximum input that can be accepted. If these are exceeded, the connector is immediately shut down, terminating the charge.

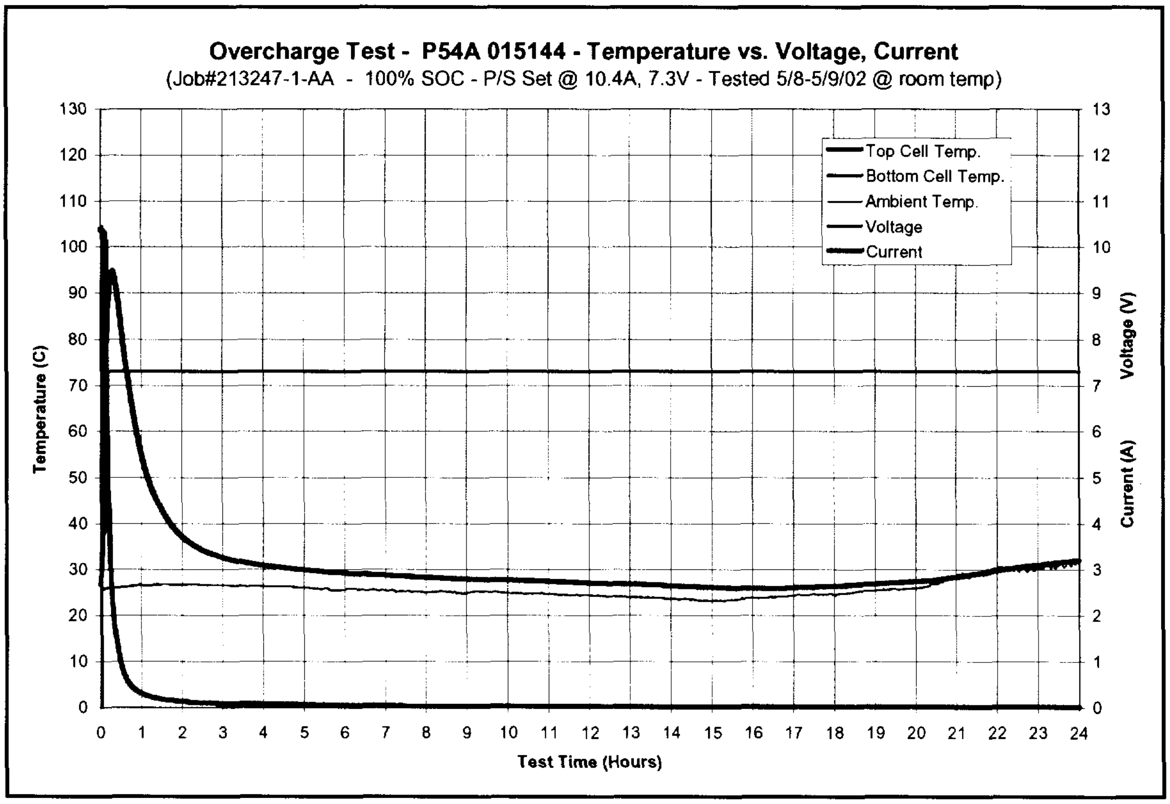


Figure 3 - 7.3V, 10.4A Overcharge on a Bare VP53109133 Cell

- In preparation for UL 1642 recognition, Valence performed 5.0V, 7.73A overcharge on six cells and 4.5V, 7.73A on two.
- In keeping with the Valence standard set for other chemistries, the UL recognition is for overcharge limited to 4.4V only. Considering that end of charge voltage is 3.65V for Saphion and not 4.2V, this is still a substantial overcharge condition. UL performed the test on 5 samples via Motorola PTS.
- Although overcharge on unprotected cells is not required by the UN tests, Valence performed 7.3V, 10.4A overcharge on 5 samples internally with passing results.
- During the N-Charge UN testing effort, 8 units were overcharged at 23.4V and 6A at Motorola PTS with four additional units tested by Valence in Nevada.
- In June of 2002, Exponent Failure Analysis Associates were retained by Valence to test prototype 18650 cells using the Saphion phosphate cathode. 40°C overcharge testing was performed on 5 cells with no events. Testing included 2 cells wired in parallel, insulated with fiberglass, and then overcharged at 20V, 3.5A peak. Temperatures reached 133°C roughly 50 minutes into the test, and then the cells began to cool on their own without venting.

Forced Discharge

When a fully discharged cell is placed in series connection with other, fully charged cells and then the resulting string is loaded, the discharged cell is forced to give up even more energy and fall below 0% state of charge. Secondary lithium cells can become highly unstable during this test.

- Valence performed UL standard forced discharge on three, 4S strings of cells internally to prepare for UL testing.
- UL discharged 5 strings of 4 cells per the 2054 standard. Maximum temperature reached was 99°C and the over discharged cells bulged slightly.
- Valence performed UN test 8 on twenty samples, 10 fresh and 10 with 50 cycles.

Oven Heating

If the temperature of a cobalt or nickel based lithium ion cell exceeds 160°C, there is a distinct danger that a thermal runaway reaction can occur. At elevated temperatures, exothermic chemical reactions are initiated which result in a rapid build up of oxygen rich gasses. Pressure will build until a safety venting device activates. At high temperatures, the internal components of Saphion cells will out gas, but no thermal runaway reactions occur. UL standards specify a heating rate of 5°C per minute for 30 minutes and a 10 minute hold at the resulting 150°C. The VP53109133 cells are not affected by this test. Valence has increased the test temperature to 300°C (572°F) in order to elicit some reaction from the cells under test.

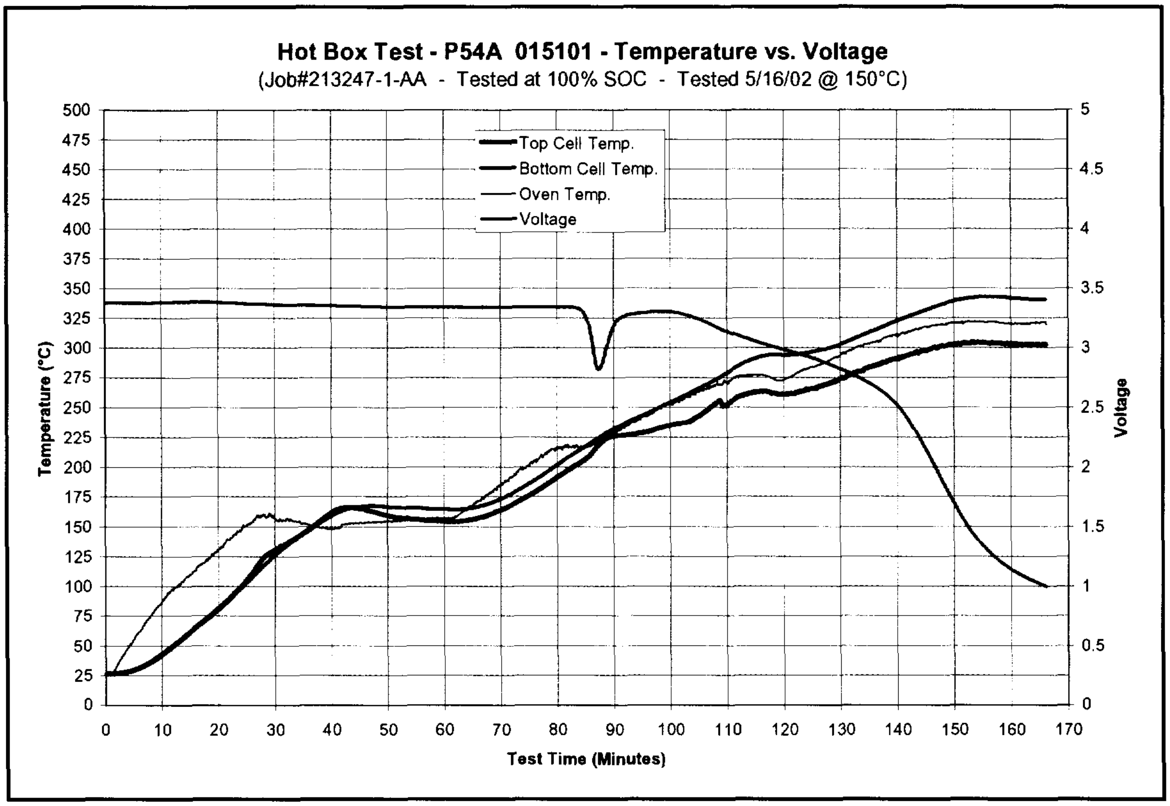


Figure 4 - Oven Heating of a VP53109133 to 300°C

In the figure, it is seen that after holding the oven temperature at 150°C for 30 minutes, it is increased to 300°C in seventy minutes. Unlike metallic burst disks, heat seals on the vacuum packaged cell will begin to soften at temperatures exceeding 100°C. Any build up of internal pressure is easily released. Components begin to break down near 200°C, and the open circuit voltage begins to fall. *Even as the oven overshoots slightly to 325°C (617°F), no reaction is seen from the sample under test*. The outer skin of the packaging is blackened by the intense heat and wisps of smoke escape from the cell interior through the now defeated heat seals.

- Oven heating to 150°C has been performed 4 times, to 230°C once, and to 300°C four times. All tests are done with fully charged cells.
- UL tested 5 samples for 1642, later electing to forgo oven testing on the N-Charge based on the results.

Nail Penetration

Nail penetration is performed for two reasons. It is a simple method to induce internal short circuits as opposed to external ones, and it is conceivable that, during crating operations, a cell being readied for shipment could be damaged by a misdirected nail (or staple, utility knife, ink pen, etc.). Cell designs that utilize laminate packaging are more vulnerable than those in metal cans, but Valence Li ion Polymer has distinct advantages during this test. Separators in "Bellcore" style cells are much thicker than those found in liquid and gel type li ion cells. In addition, the uniform polymer matrix found in all three components of a Valence cell will act together to "heal" the damage caused by the nail, insulating it from the conductive substrates. Often, even after the standard 5 penetrations by the 3mm steel nail, no voltage drop is seen. Furthermore, if phosphate cathodes are used, the potential for thermal runaway initiated by short induced localized heating is eliminated.

Flame Exposure

Two fire immersion tests are included in Underwriters Laboratories' 2054 standard. Test 22 uses a cheesecloth panel to detect flaming particles traveling more than 3 feet from the burning cell. Test 23 encloses the sample in a wire mesh cage. The test is failed if any portion of the battery escapes the cage. A propane Bunsen burner is used. Propane in air typically burns at 1600°C, and for verification, UL requires a steel mesh screen be in place underneath the sample. Steel will glow red-hot at 1200°C (2200°F).

Flame exposure testing on lithium metal cells can be quite spectacular as lithium is a very energetic material. Li ion cells contain no lithium metal, but when ignited, the combination of liquid electrolyte and the release of large amounts of oxygen as the lithiated cobalt oxide decomposes can result in a significant discharge of energy. Valence Saphion cells contain very little electrolyte and do not release oxygen easily.

Reactivity is tied somewhat to state of charge. Below 50% state of charge, Saphion cells will flare quickly as the electrolyte burns off and then proceed to simply smoke like burning plastic. A 30% state of charge cell can be cooked for over an hour and not react beyond that initial, weak flame. (The N-Charge Battery Pack is shipped from the manufacturer at 30-50% SoC.) At higher states of charge, a secondary vent reaction can be seen minutes after the initial small flare. Even in the presence of the burner, the vent products most often do not catch fire. If the secondary vent products do combust, the resulting flames die out in seconds. So quickly, in fact, that it is not possible for the "flaming" vent reaction to propagate fire to an adjacent cell, let alone a cheesecloth screen 3 feet away. Phosphate cells do not like to burn. At any point during the test, if the Bunsen is removed, the cell will self extinguish.

The N-Charge battery is enclosed in GE Cycoloy 6600, rated 94V-0 but de-rated to 94V-2 because of the thin molding. It melts and flows at 500°C, and does not burn during flame exposure testing. Often, after burn tests are completed on N-Charge packs, portions of the enclosure will be melted around totally intact component cells. 500°C and they did not even vent smoke.

- Internally, Valence has conducted flame exposure testing on 2 cells each at 0%, 30%, 70%, and 100% state of charge.
- To investigate propagation, tests have been conducted with Bunsen termination after the initial flare and after several minutes of heating. Even 100% SoC cells quickly self extinguish once the flame source is removed. Multiple cells in close proximity to the one that was directly exposed were not damaged.
- Two N-Charge units have been burned at 30% SoC and three at 100%.
- UL has conducted flame exposure on 20 samples at 100% SoC, including ten 65Wh packs and ten 130Wh packs.

Conclusion

The above is a summary of the total body of testing Valence Technology has accumulated to date on its proprietary phosphate cathode lithium ion technology, trademarked as Saphion. It does not include many tests performed while the product was in development, or some of the more enclosure design driven tests. Examples are 250lb crush, drop impact, or the 70°C "Mold Stress" test. Copies of third party certifications and the UN test reports are kept on file at Valence in Austin, Texas, or the certification bodies can be contacted directly for more information using the references provided by Table 1.

Appendix – Testing Summary Tables

UL 1642 - Standard for Lithium Batteries, Third Edition
File MH25828
Model VP53109133, May 15th, 2002

		Sample Size	Result	Comments
Short Circuit @ 60C	*Short the battery terminals after test sample is at 60 degrees Celsius (140 F)*	5	Pass	Maximum temperature recorded was 81C
Short Circuit @ 23C	*Short the battery terminals after test sample is at room temperature*	5	Pass	Maximum temperature recorded was 66C
Abnormal Charging	*Charge at 3X manf. recommended rate for 48hrs*	5	Pass	Charge current was 14.85A and 4.4V
Crush Test	*3000lb flat plate crush*	5	Pass	
Impact Test	*20lb mass dropped from 24" onto 5/8" bar*	5	Pass	
Shock Test	*75g avg over 3ms with peak 125g to 175g*	NA	Pass	Accepted without testing based on experience with Valence Cells
Vibration	*Simulated transportation vibration*	NA	Pass	Accepted without testing based on experience with Valence Cells
Heating	*5C/min increase in temperature to 150C (302F) where it is held for 10 minutes*	5	Pass	
Temperature Cycling	*70C for 4 hrs, 20C for 2 hours, -40C for 4hrs, 10 cycles*	NA	Pass	Accepted without testing based on experience with Valence Cells
Altitude Simulation	*6hrs storage at 11.6kPa absolute, 20C*	NA	Pass	Accepted without testing based on experience with Valence Cells

UL 2054 - Household and Commercial Batteries
File MH28367
Model 065H001, May 15th, 2002
Model 130HL01, June 26th, 2002

		Model	Sample Size	Result	Comments
Short Circuit @ 60C	*Short the battery terminals after test sample is at 60 degrees Celsius (140 F)*	065H001	5	Pass	UL Listed Fuse limits discharge current to 5A
		130HL01	5	Pass	
Short Circuit @ 23C	*Short the battery terminals after test sample is at room temperature*	065H001	5	Pass	UL Listed Fuse limits discharge current to 5A
		130HL01	NA	Pass	By similarity
Abnormal Charging	*Charge at 3X manf. recommended rate for 48hrs*	065HL001	5	Pass	Charge current was 7.5A (Motorola/UL)
		130HL01	5	Pass	Charge current was 5.0A (UL)
Abusive Overcharge	*Charge at 10X recommended rate until temperature of cells return to ambient*	065H001	5	Pass	9.9A, 19.0V, max temp was 50C
		130HL01	NA	Pass	By similarity
Forced Discharge	*(Cell Test) Connect Fully discharged cell in series with string of 3 charged cells*	VP53109133	5	Pass	Sample bulged, max temp was 99C
Limited Power Source	*Load battery with Nichrome wire wrapped in cheesecloth for 60s. Imax = 8A, no ignition*	065H001	3	Pass	UL Listed Fuse limits discharge current to 5A
		130HL01	3	Pass	
Crush Test	*3000lb flat plate crush*	both	NA	Pass	Accepted without testing based on cell results
Impact Test	*20lb mass dropped from 24" onto 5/8" bar*	both	NA	Pass	Accepted without testing based on cell results
Shock Test	*75g avg over 3ms with peak 125g to 175g*	both	NA	Pass	Accepted without testing
Vibration	*Simulated transportation vibration*	both	NA	Pass	Accepted without testing
Battery Enclosure	*Can not be opened with simple tools, classed 94V-2 or less flammable*	both	NA	Pass	
250lb Crush	*250lb over 1sq.ft.*	both	NA	Pass	Accepted without testing
Mold Stress Relief	*70C (158F) for 7hrs*	065H001	3	Pass	
		130HL01	NA	Pass	By similarity
Drop Impact Test	*Three 1m drops onto concrete in orientations most likely to produce adverse results*	065H001	3	Pass	Outer enclosure can crack, but no protective devices are compromised or hazardous material exposed
		130HL01	3	Pass	
Flaming Particle	*Fire Exposure with cheesecloth panel 3 ft away, cloth can not ignite*	065H001	5	Pass	No Explosion, test discontinued after sample consumed
		130HL01	5	Pass	
Projectile Test	*Fire Exposure with sample in wire mesh box, no portion of the battery shall escape box*	065H001	5	Pass	No Explosion, test discontinued after sample consumed
		130HL01	5	Pass	
Heating	*5C/min increase in temperature to 150C (302F) where it is held for 10 minutes*	both	NA	Pass	Accepted without testing based on cell results
Temperature Cycling	*70C for 4 hrs, 20C for 2 hours, -40C for 4hrs, 10 cycles*	both	NA	Pass	Accepted without testing

UN Manual of Tests and Criteria
Section 38.3, Lithium Batteries
Model VP53109133

		Sample Size	Result	Comments
Altitude	*6hrs storage at 11.6kPa absolute, 20C*	20	Pass	
Thermal Cycling	*75C for 6 hrs, 30minute transition, -40C for 6hrs, 10 cycles*	20	Pass	
Vibration	*Simulated Transportation Vibration*	20	Pass	
Shock	*150g Peak with a 6ms pulse duration*	20	Pass	
External Short Circuit	*Short circuit at 55C case temperature*	20	Pass	
Impact	*9.1kg mass from 61cm onto 15.8mm dia bar*	20	Pass	
Overcharge	*Charge batteries at 23.4V and 6A for 24 hours*	NA	NA	Constrained cells pass, unconstrained cells vent (still meet criteria)
Forced Discharge	*Series with 12Vdc supply, 5.2A, 60minutes*	20	Pass	Component Cells pass this test

UN Manual of Tests and Criteria
Section 38.3, Lithium Batteries
Model 130HL01

		Sample Size	Result	Comments
Altitude	*6hrs storage at 11.6kPa absolute, 20C*	16	Pass	
Thermal Cycling	*75C for 6 hrs, 30minute transition, -40C for 6hrs, 10 cycles*	16	Pass	
Vibration	*Simulated Transportation Vibration*	16	Pass	
Shock	*150g Peak with a 6ms pulse duration*	16	Pass	
External Short Circuit	*Short circuit at 55C case temperature*	16	Pass	
Impact	*9.1kg mass from 61cm onto 15.8mm dia bar*	20	Pass	Test is conducted on component cells (VP53109133)
Overcharge	*Charge batteries at 23.4V and 6A for 24 hours*	8	Pass	
Forced Discharge	*Series with 12Vdc supply, 5.2A, 60minutes*	NA	NA	Component Cells pass this test

Testing Conducted Internally by Valence

Log No.	Date of Test	Cell S/N	Cell Type	Type Test	Initial % SOC	Pass/ Fail		Additional Information
Short Circuit								
34	3/7/2002	003374	P54A	60°C Short Circuit	100	Pass	T<150C	UL Confidence Testing
35	3/7/2002	150371	P54A	60°C Short Circuit	100	Pass	T<150C	UL Confidence Testing
36	3/7/2002	003408	P54A	60°C Short Circuit	100	Pass	T<150C	UL Confidence Testing
37	3/7/2002	150372	P54A	60°C Short Circuit	100	Pass	T<150C	UL Confidence Testing
38	3/7/2002	002879	P54A	60°C Short Circuit	100	Pass	T<150C	UL Confidence Testing
39	3/7/2002	003247	P54A	60°C Short Circuit	100	Pass	T<150C	UL Confidence Testing
53	3/20/2002	003845+3	P54A	60°C ShortCircuit(4S)	100	Pass	T<150C	UL Confidence Testing
54	3/20/2002	002889+3	P54A	60°C ShortCircuit(4S)	100	Pass	T<150C	UL Confidence Testing
55	3/21/2002	003065+3	P54A	60°C ShortCircuit(4S)	100	Pass	T<150C	UL Confidence Testing
56	3/21/2002	003830+3	P54A	60°C ShortCircuit(4S)	100	Pass	T<150C	UL Confidence Testing
129	5/22/2002	010772	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
130	5/22-5/23/02	009433	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
131	5/23/2002	008302	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
132	5/23/2002	008209	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
133	5/23/2002	009469	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
134	5/23-5/24/02	008295	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
135	5/24/2002	008226	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
136	5/28/2002	008259	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
137	5/28/2002	008206	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
138	5/28-5/29/02	008261	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
139	5/29/2002	008254	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
140	5/29/2002	008260	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
141	5/29/2002	008263	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
142	5/29/2002	008294	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
143	5/29/2002	008297	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
144	5/29/2002	008303	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
145	5/29-5/30/02	008282	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
146	5/30/2002	009328	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
147	5/30/2002	009370	P54A	55°C Short Circuit	0	Pass	T<150C	UN Testing
148	5/30-5/31/02	008208	P54A	55°C Short Circuit	100	Pass	T<150C	UN Testing
178	8/9/2002	003358	P54A	60°C Short Circuit	100	Tab	Blew	No-test, circuit @ 11mΩ, S/B @ 21mΩ
186	8/13/2002	024192	P54A	60°C Short Circuit	100	Pass	T<150C	
187	8/13/2002	026924	P54A	60°C Short Circuit	100	Pass	T<150C	
202	8/20/2002	046932	P54A-LT	60°C Short Circuit	100	Pass	T<150C	
203	8/20/2002	046931	P54A-LT	60°C Short Circuit	100	Pass	T<150C	
204	8/20/2002	046930	P54A-LT	60°C Short Circuit	100	Pass	T<150C	
205	8/20/2002	046929	P54A-LT	60°C Short Circuit	100	Pass	T<150C	
206	8/20/2002	046927	P54A-LT	60°C Short Circuit	100	Pass	T<150C	
Altitude Exposure								
50	3/19/2002	15 Cells	P54A	Altitude Exposure	0/50/100	Pass		UL Confidence Testing
74	4/8/2002	20 Cells	P54A	DOT Altitude Exposure	0/100	Pass		UN Testing
Thermal Cycling								
52	3/20-3/25/02	15 Cells	P54A	Themal Cycling	0/50/100	Pass		UL Confidence Testing
75	4/9-4/16/02	20 Cells	P54A	DOT Themal Cycling Test	0/100	Pass		UN Testing
Fire Exposure								
57	3/22/2002	N-Charge1	P54A	Fire Exposure	100	Pass		UL Confidence Testing
58	3/22/2002	003214	P54A	Fire Exposure	100	Pass		UL Confidence Testing
59	3/22/2002	003235	P54A	Fire Exposure	100	Pass		UL Confidence Testing
155	7/12/2002	Nchg #5	Pack	Fire Exposure	100	Pass		
222	10/7/2002	Nchg #1	Pack	Fire Exposure	100	Pass		Flame positioned under one quadrant
223	10/7/2002	Nchg #3	Pack	Fire Exposure	100	Pass		Flame positioned at center of one side overlapping edge
224	10/9/2002	087909+3	P54A	Fire Exposure	100	Pass		4 cells stacked on top of each other,
225	10/9/2002	092328+7	P54A	Fire Exposure	100	Pass		8 cells positioned like an N-Charge
226	10/9/2002	087833	P54A	Fire Exposure	0	Pass		Single cell on ringstand
227	10/9/2002	087786	P54A	Fire Exposure	0	Pass		Single cell on ringstand
230	10/15/2002	084692	P54A	Fire Exposure	30	Pass		Single cell on ringstand
231	10/15/2002	087802	P54A	Fire Exposure	30	Pass		Single cell on ringstand
232	10/15/2002	084707	P54A	Fire Exposure	50	Pass		Single cell on ringstand
233	10/15/2002	087810	P54A	Fire Exposure	50	Pass		Single cell on ringstand
234	10/15/2002	087865+7	P54A	Fire Exposure	100	Pass		8 cells positioned like an N-Charge
	10/18/2002	092352	P54A	Fire Exposure	70	Pass		
	10/18/2002	092335	P54A	Fire Exposure	70	Pass		

Log No.	Date of Test	Cell S/N	Cell Type	Type Test	Initial % SOC	Pass/ Fail		Additional Information
Flat Plate Crush								
49	3/18/2002	N-Charge1	P54A	Flat Plate Crush	?	Pass		
Forced Discharge								
44	3/8/2002	003346+3	P54A	Forced Discharge(4S)	0/100	Pass		UL Confidence Testing
45	3/11/2002	003575+3	P54A	Forced Discharge(4S)	0/100	Pass		UL Confidence Testing
47	3/14/2002	003507+3	P54A	Forced Discharge(4S)	0/100	Pass		UL Confidence Testing
77	4/16/2002	150265	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
78	4/16/2002	150266	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
79	4/16-4/17/02	150268	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
80	4/17/2002	150270	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
81	4/17/2002	150271	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
82	4/17-4/18/02	150272	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
83	4/18/2002	150273	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
84	4/18/2002	150277	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
85	4/18-4/19/02	150189	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
90	4/19/2002	150193	P54A	Force Dischg 12V,5.2A	0	Pass		UN Testing
99	5/3/2002	015119	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
104	5/3/2002	015134	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
107	5/3-5/6/02	015145	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
110	5/6/2002	015296	P54A	Force Dischg 12V,5.2A	50 XX	Pass		**Doesn't count, ran from 50%, S/B 100 100%**
111	5/6/2002	015274	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
113	5/6-5/7/02	015283	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
115	5/7/2002	015289	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
116	5/7/2002	015295	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
117	5/7/2002	015298	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
118	5/7-5/8/02	015303	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
119	5/7-5/8/02	015360	P54A	Force Dischg 12V,5.2A	100	Pass		UN Testing
Oven Heating								
40	3/8/2002	003096	P54A	Hot Box @ 150°C	100	Pass		UL Confidence Testing
41	3/8/2002	003511	P54A	Hot Box @ 150°C	100	Pass		UL Confidence Testing
42	3/8/2002	150373	P54A	Hot Box @ 150°C	100	Pass		UL Confidence Testing
43	3/8/2002	150374	P54A	Hot Box @ 150°C	100	Pass		UL Confidence Testing
60	3/26/2002	003254	P54A	Hot Box @ 230°C	100	Pass		
61	3/26/2002	003242	P54A	Hot Box @ 300°C	100	Pass		
127	5/16/2002	015101	P54A	Hot Box @ 150°C/300°C	100	Pass		
128	5/17/2002	015211	P54A	Hot Box @ 150°C/300°C	100	Pass		
207	8/21/2002	046927	P54A-LT	Hot Box @ 150°C/300°C	100	Pass		
Round Bar Impact								
51	3/19/2002	N-Charge2	P54A	Impact (3 times)	50	Pass		
76	4/15-4/16/02	150264	P54A	Impact (1 time)	0	Pass		
86	4/18/2002	150279	P54A	Impact (Flat - 2 times)	0	Pass		
87	4/18/2002	150190	P54A	Impact (Flat - 2 times)	0	Pass		
88	4/18/2002	150191	P54A	Impact (Flat - 2 times)	0	Pass		UN Testing
89	4/18/2002	150192	P54A	Impact (Flat - 2 times)	0	Pass		UN Testing
91	4/19/2002	150195	P54A	Impact (Flat - 2 times)	0	Pass		UN Testing
92	4/19/2002	150196	P54A	Impact (Flat - 2 times)	0	Pass		UN Testing
93	4/19/2002	150198	P54A	Impact (Flat - 2 times)	0	Pass		UN Testing
94	4/19/2002	150199	P54A	Impact (on edge - once)	0	Pass		UN Testing
95	4/19/2002	150200	P54A	Impact (on edge - once)	0	Pass		UN Testing
96	4/23/2002	150255	P54A	Impact (on edge - once)	0	Pass		UN Testing
97	4/23/2002	150256	P54A	Impact (on edge - once)	0	Pass		UN Testing
98	4/23-4/24/02	150257	P54A	Impact (on edge - once)	0	Pass		UN Testing
100	5/3/2002	015137	P54A	Impact (Flat - 2 times)	50	Pass		UN Testing
101	5/3/2002	015222	P54A	Impact (Flat - 2 times)	50	Pass		UN Testing
102	5/3/2002	015290	P54A	Impact (Flat - 2 times)	50	Pass		UN Testing
103	5/3/2002	015148	P54A	Impact (Flat - 2 times)	50	Pass		UN Testing
105	5/3/2002	015278	P54A	Impact (Flat - 2 times)	50	Pass		UN Testing
106	5/3/2002	015284	P54A	Impact (on edge - once)	50	Pass		UN Testing
108	5/3/2002	015362	P54A	Impact (on edge - once)	50	Pass		UN Testing
109	5/3/2002	015307	P54A	Impact (on edge - once)	50	Pass		UN Testing
112	5/6/2002	015291	P54A	Impact (on edge - once)	50	Pass		UN Testing
114	5/6/2002	015301	P54A	Impact (on edge - once)	50	Pass		UN Testing
125	5/15/2002	015279	P54A	Impact (on edge - once)	100	Pass		
126	5/15-5/16/02	015294	P54A	Impact (on edge - once)	100	Pass		

Log No.	Date of Test	Cell S/N	Cell Type	Type Test	Initial % SOC	Pass/ Fail		Additional Information
Nail Penetration								
228	10/10/2002	088030	P54A	Nail Penetration	100	Pass		
229	10/10/2002	088016	P54A	Nail Penetration	100	Pass		
Overcharge								
6	2/8-2/11/02	001314	P54A	R/T OC 4.5V,7.73A	100	Pass		
7	2/8-2/11/02	001407	P54A	R/T OC 4.5V,7.73A	100	Pass		
23	2/15-2/28/02	149550	P54A	R/T OC 5.0V,7.73A	30	Pass		
24	2/15-2/28/02	149562	P54A	R/T OC 5.0V,7.73A	30	Pass		
48	3/15-3/20/02	002894+3	P54A	R/T OC 20V,7.73A(4S)	30	Pass		
62	3/27/2002	002959	P54A	R/T OC .0V, A	30	Pass		
63	3/28/2002	002900	P54A	R/T OC .0V, A	30	Pass		
66	4/1/2002	003344	P54A	R/T OC .0V, A	30	Pass		
69	4/3/2002	003095	P54A	R/T OC .0V, A	30	Pass		
120	5/8-5/9/02	015144	P54A	R/T OC 7.3V, 10.4A	100	Pass		Constrained, 24 hours duration
121	5/8-5/9/02	015151	P54A	R/T OC 7.3V, 10.4A	100	Pass		Constrained, 24 hours duration
122	5/13-5/14/02	015297	P54A	R/T OC 7.3V, 10.4A	100	Pass		Constrained, 24 hours duration
123	5/13-5/14/02	015302	P54A	R/T OC 7.3V, 10.4A	100	Pass		Constrained, 24 hours duration
124	5/14/2002	015223	P54A	R/T OC 7.3V, 10.4A	100	Vent		Unconstrained, Still meets UN criteria
149	6/18-6/19/02	Nchg #1	Pack	R/T OC 23.4V, 6.0A	100	Pass		
150	6/20-6/21/02	Nchg #2	Pack	R/T OC 23.4V, 6.0A	100	Pass		
151	6/20-6/21/02	Nchg #3	Pack	R/T OC 23.4V, 6.0A	100	Pass		
152	6/20-6/21/02	Nchg #4	Pack	R/T OC 23.4V, 6.0A	100	Pass		
	6/12/2002	707967	P1 18650	40C OC 7V, 1.75A	100	Pass		Exponent Testing
	6/12/2002	707969	P1 18650	40C OC 7V, 2.25A	100	Pass		Exponent Testing
	6/12/2002	707968	P1 18650	40C OC 20V, 1.75A	100	Pass		Exponent Testing
	6/12/2002	707966,65	P1 18650	40C OC 20V, 3.5A	100	Pass		Exponent Testing on 2P config

N-Charge™ System vs. 80Wh Laptop Pack, Flame Exposure, As Shipped
Video Narrative
Plus Oven Heating, Nail Penetration, Flat Impact, and Edge Impact on 100% State of Charge Component Cells

Video 1 - Flame Exposure, N-Charge System vs. 80Wh Laptop Battery, As Shipped State of Charge

- For this test, Valence acquired through retail channels a replacement battery pack, distributed by a Tier 1 laptop manufacturer for one of their products. Twelve, 1.8Ah Li ion cells were assembled within, creating an 80Wh configuration. The battery was removed from its shipping material and subjected to flame exposure in an "as received" condition. For comparison, a Valence 130Wh N-Charge system was also tested in an "as shipped" condition and the films synchronized. In the split screen, the N-Charge system is in the upper portion, the 80Wh pack in the lower.

Video 1 - Flame Exposure, N-Charge vs 80Wh Laptop Battery, As Shipped State of Charge (SoC)

- 30% SoC N-Charge system is at top of screen, "as received" Laptop Pack is at bottom (estimated 48% SoC), video timing is synchronized
- 0:04, Bunsen is lit.
- 0:14, Jump ahead in time to 5:18 into the test. No events from either unit.
- 0:19, First flare and small flames from pack as heavy vapor burns (5:23 in test)
- 1:30, Big flare from laptop battery (6:30)
- 2:00 – 4:30, Activity from the burning laptop battery includes flares and jets of sparks and flame
- Burn test on 30% SoC N-Charge system continues for over 60 minutes total without event. Nothing except light smoke, no flame.
- From the flare at 6:30, the laptop pack burns for roughly another 6 minutes
- 5:37, Close-ups of N-Charge system pack post test
- 6:08, Close-ups of laptop battery post test

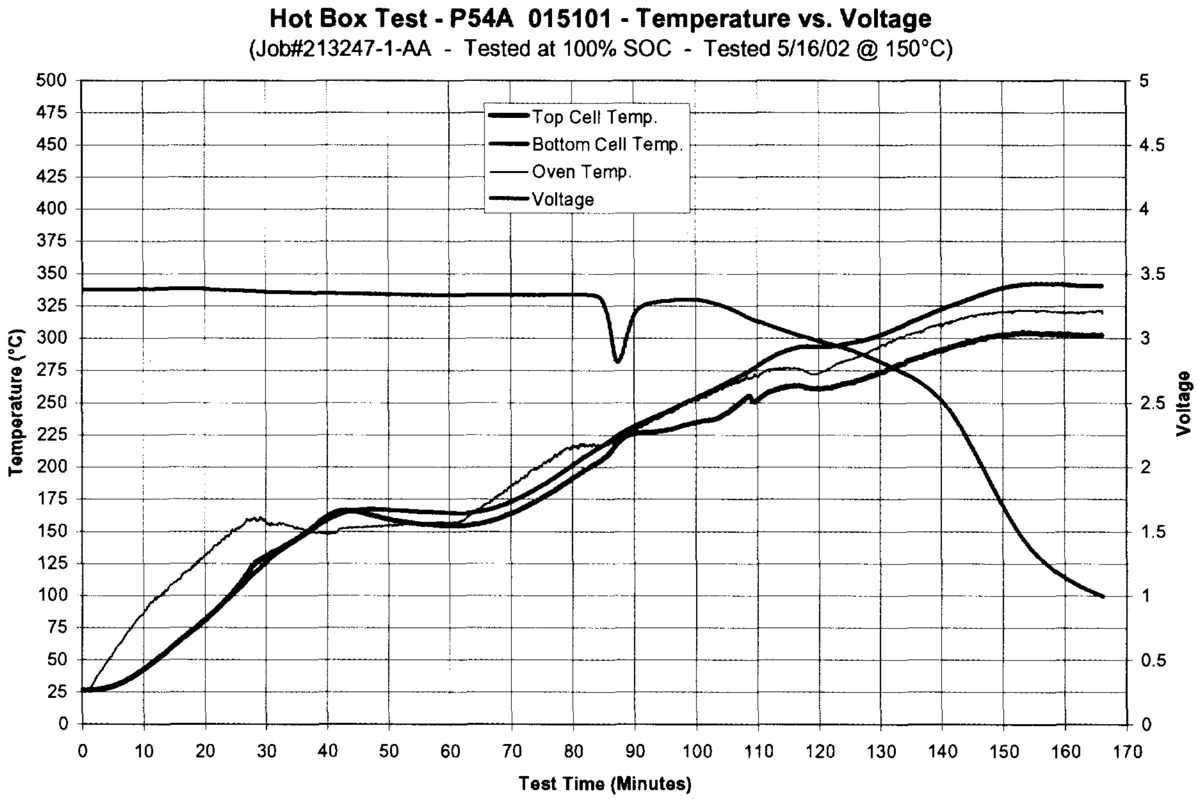
Video 2 - Oven Heating Test

Oven heating common cobalt or nickel based lithium ion cells to temperatures in excess of 160°C often results in a "thermal runaway" reaction. Valence Saphion cells are not capable, chemically, of such a reaction. To demonstrate, a component cell from an N-Charge system battery is slowly heated from room temperature up to 300°C (572°F). Time compressed video shows the cell's benign reaction to this abusive environment.

Video 2 - Oven Heating Test

- UL 1642 - Test 18A with added ramp to 300°C
- A fully charged cell is placed in a circulating air oven. The ambient temperature is raised, 5°C /minute up to 150°C (302°F) where it is held for 10 minutes.
- No reaction, save for some slight inflation, is seen with Saphion cells during this test. In an attempt to induce a failure, the temperature is held at 150°C for 30 minutes then ramped to 300°C (572°F) in 70 minutes.
- 0:00, 9:07am - Test begins at room temperature
- 0:05, 9:37am - 155°C in oven, cell @ 130°C is slightly inflated
- 0:12, 10:07am - Cell @ 157°C, no change from 130°C
- 0:18, 10:37am - Cell now at 232°C, voltage spiked down for a short period minutes earlier at 230°C then recovered. Cell is still intact. Smoke is seen as the plastic outer surface/label cooks away.
- 0:24, 11:07am - Oven at 275°C, bottom of cell reads 293°C, top reads 260°C (top T/C has come loose, now 1" above cell). Voltage has been dropping since 255°C
- 0:30, 11:37am - Oven at 320°C (overshoot), bottom of cell reads 340°C. Voltage has dropped down to 1.6V here at 150m into the test
- 0:38, 11:53am - Oven is held at 320°C for 20m after the 150m mark. Cell temperature readings stay the same. Cell seems to have deflated as the heat seals usually fail at around 200°C.
- 0:42, 11:55am - Oven door is opened to reveal the cell, blackened but intact.

Oven Heating to 300°C, 100% State of Charge Cell



Video 3 - 3mm Steel Nail Penetration Test

- Similar to test in JSBA Standard
- Conducted at room temperature on fully charged cell
- Valence routinely performs 5 or more penetrations, attempting to initiate failure
- 0:06, Penetration 1, no event
- 0:23, Penetration 2, no event
- 0:37, Penetration 3, no event
- 0:53, Penetration 4, no event
- 1:08, Penetration 5, no event

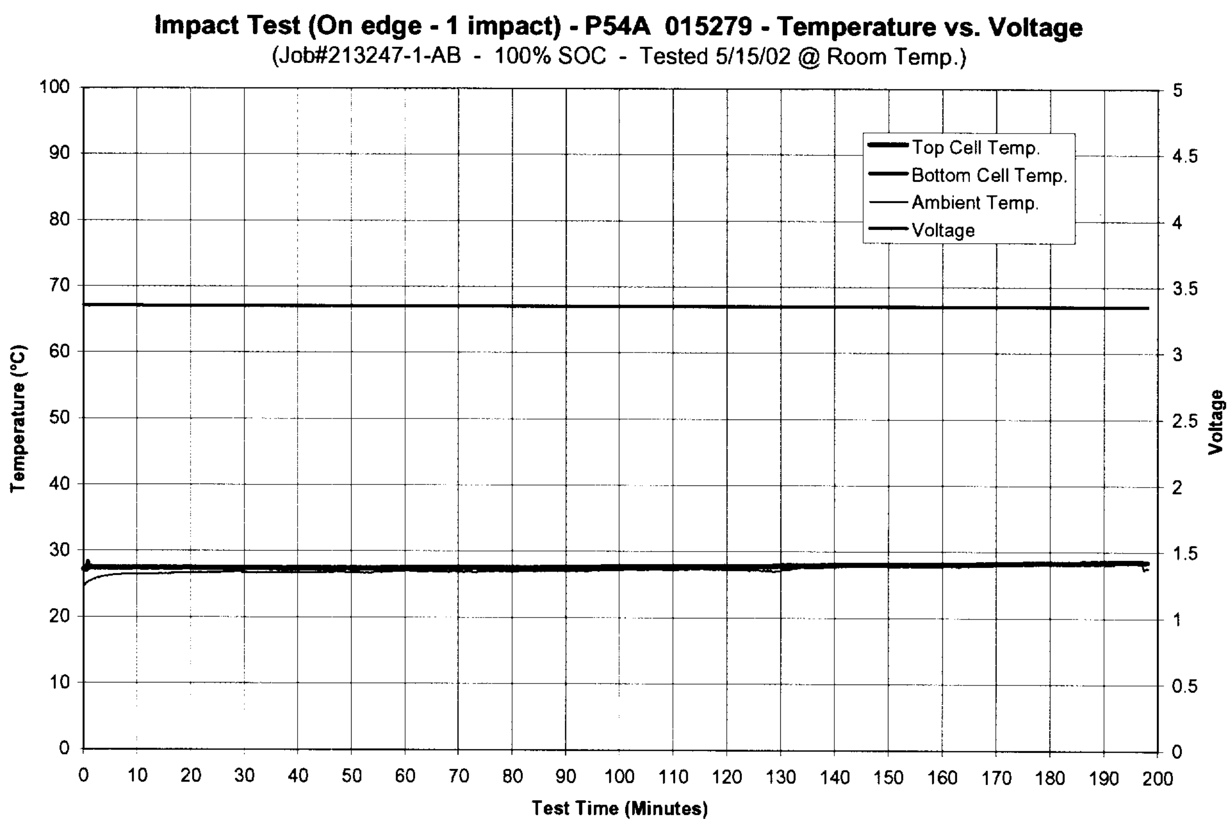
Video 4 - Flat Impact

- Conducted at room temperature on fully charged cell
- Per UL 1642 and the UN Tests, a 15.8mm diameter round bar is laid across the cell. A 9.1kg mass is dropped onto the bar from 61cm.
- 0:04, Impact 1, no event
- 0:14, Impact 2, no event
- 0:29, Impact 2 replayed at 40% speed

Video 5 - Edge Impact

- UN Test 6
- Conducted at room temperature on fully charged cell
- A repeat of the flat impact with the the round bar placed across the narrow edge of the "prismatic" cell
- 0:04, Impact 1, no event
- 0:13, Impact 1 replayed at 40% speed
- For UN qualification, edge impact was performed on 5 cells at 0% SoC and 5 Cells at 50% SoC. Valence repeated the test on 2 cells at 100%, and the results were the same.

Edge Impact, 100% State of Charge Cell



Five, 50% State of Charge, Edge Impact Specimens from VP53109133 UN Testing